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APPENDIX

PRINCIPLES AND PRACTICE OF DESIGN OF SOIL COVER FOR WASTE ASBESTOS IN NORTHERN AREAS

WITH

CALCULATION OF MINIMUM COVER IN OPEN AREAS OF THE JOHNS-MANVILLE ASBESTOS DISPOSAL SITE AT WAUKEGAN, ILLINOIS

by
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Purpose and Applicability

This paper is written in response to the Feasibility Study submitted by Johns-Manville Corporation (J-M) for covering waste asbestos at their manufacturing plant in Waukegan, Illinois. Its purpose is four-fold: (1) to lay out general principles of soil-cover design in northern areas subjected to yearly freezing and thawing; (2) to present a brief description of methods currently being used in New Hampshire to contain asbestos waste by means of non-frost-susceptible soil layers; (3) to present calculations on the specific thickness of cover required in the open disposal areas of the J-M Waukegan plant using frost-susceptible soil as proposed by J-M; and (4) to evaluate the cover design of 18 in. for open areas proposed by J-M in the Feasibility Study as the best alternative.

Cover designs proposed in the Feasibility Study for roadways, dikes, and levees adjacent to settling basins are deemed acceptable as presented. Consequently, this paper considers only the required and the proposed soil cover designs for open storage areas of the J-M site, which include all non-active waste piles and portions of active waste piles as they are filled and removed from active service. It is understood that there are currently three active solid waste disposal areas on the site: an asbestos disposal pit, a miscellaneous disposal pit, and a sludge disposal pit (Fig. 1).

The Hazard

Asbestos is a naturally occurring fibrous silicate mineral that has been used in a variety of manufactured products at the J-M Waukegan plant since 1922. It is noncombustible, resistant to oxidation or other corrosion, has a high tensile strength and low electrical and thermal conductivities. It was first used as thermal insulation for steam engines.

Various binders are mixed with the asbestos fibers, including asphalt, Portland cement and other silicates, plastics, starches, and textiles. At the Waukegan site the major type of waste is from the manufacture of asbestos-cement pipe, roofing products, and insulating materials. The major binding materials are Portland cement and asphalt.

The medical hazard from asbestos arises when the product becomes friable; the fibers are generally between 0.1 and 10 microns in length and when separated from the binder are easily airborne. It has been found that fibers of chrysotile, the primary asbestos mineral, are especially hazardous when they are between 3 and 5 microns in length and approximately 1 micron in width. When inhaled they cause cancer of the lungs, chest, and abdomen, as well as noncancerous respiratory diseases.

According to the National Institute of Health, (DHEW PUBL NO. NIH78-1622, May 1978) studies have shown that industrial workers, their families, and other persons living or working near the manufacturing operations are endangered. Those exposed to asbestos fibers have been found to have 5 times the chance of developing an asbestos-related disease as does the general population. Among asbestos-insulation workers the mortality rate is increased 2 to 10 times; cigarette smoking increases the health hazard at all levels by an additional order of magnitude for both workers and non-workers.

<u>The Problem</u>

Since about 1922, hundreds of thousands of tons of industrial waste containing asbestos have been disposed of at the Waukegan site by Johns-Manville Corporation. Through erosion, or through incomplete burial in the first place, many deposits are now exposed or lie less than a foot below the surface. Upon exposure to ground water, and particularly to rain, sunlight, air, and wind, the cementing agents break down and release the fibers to the atmosphere. Once the fibers are airborne they are known to remain in the atmosphere for long periods of time. There does not appear to be a safe threshold of exposure, so that all levels of airborne fibers pose a serious long-range health threat.

Because excavation renews the exposure potential, the safest solution to this threat is to containerize the asbestos materials permanently. In the case of large deposits such as those considered here, containment is accomplished by means of burial under appropriate layers of soil. In the Waukegan area, and at other locations in the United States where seasonal freezing occurs, there is the further danger that repetitious freezing and thawing may gradually bring the asbestos products back to the surface. As with stones and other large particles, broken scraps of asbestos represent inclusions which tend to move differentially upward with each freeze/thaw cycle. In old deposits, scraps of asbestos board or other products oriented vertically and partially protruding from the surface, while the surrounding area may be strewn with a pavement of scraps lying flat on the surface (Fig. 2), are direct evidence that progressive migration has been taking place for a long time.

The problem in areas of seasonal frost is to utilize appropriate covering techniques so that the asbestos material will remain buried essentially at the original cover depth with a confidence level of at least 90% for the first 100 years. In the long run this period may not be sufficiently conservative, but at present it appears to be an acceptable expedient.

Principles of On-Site Containment in Areas of Seasonal Frost

Because asbestos waste from commercial manufacturing processes becomes hazardous to human health when individual fibers become airborne, the over-riding principle in the control of these wastes is to make certain that no fibers reach the atmosphere. As mentioned above, on-site containerization of the waste by burial with soil layers sufficient to prevent the entrance of significant numbers of fibers to the covering soil for a period in excess of 100 years is the primary method recommended. The burial may be in a controlled disposal area, or it may be on-site. The latter method is the preferred one, inasmuch as excavation of the asbestos waste for any reason reintroduces the potential health hazard. Excavation is normally used as a last resort.

Regulations controlling excavation, transportation from the site, and burial in a commercial disposal area are currently in force (EPA/530-WS-85-007, May 1985) and govern any portion of the asbestos waste which does not remain on-site. This type of disposal is not discussed further here, but if the disposal area is in a region subject to seasonal frost, current regulations pertaining to the depth and type of burial in these facilities should be reviewed in the light of the provisions outlined here.

On-site containment is normally less expensive per cubic yard of material, but it carries with it the potential that the asbestos waste may again reach the ground surface (and the atmosphere) through removal of the protective cover by construction equipment or by recreational vehicles, or through erosion from wind and water resulting from insufficient maintenance of the site. Occurrences such as these may be prevented by means of administrative measures. On the other hand, in those cases in which asbestos may be brought to the surface through the action of repetitive freezing and thawing, protective measures must be incorporated by means of appropriate design at the time of the restoration of the site.

It is generally known that stones or other materials larger in size than the surrounding grains of soil move upward with each cycle of freezing and thawing. Sometimes a pocket of soil where such movement has continued for many years is termed a <u>frost boil</u> because of the resemblance to bubbles in a boiling pot of water. The need for spring harvesting of stones brought to the surface of a newly tilled field by frost action is also well known among farmers of northern states.

The observed differential movement over a winter occurs because the upper portion of a large particle becomes frozen-in first, while the lower portion is still surrounded by unfrozen soil (Fig. 2). Heaving of the adjacent soil by the formation of ice lenses moves the frozen layers upward, carrying the frozen-in particles along. When the ground thaws, the process is reversed; the lower portion remains frozen in place while the soil around the upper part thaws and settles. The result of this sequence is that a particle with a vertical dimension larger than the majority of soil grains moves upward relative to those grains in winter, and does not completely return to place in the spring.

The amount of movement with each instance of freezing and thawing has not been measured, but may be estimated to be approximately 25 percent of the vertical dimension of a particle. Thus, a 4-inch piece of buried sheet asbestos standing upright in the soil could move toward the surface at a rate of about 1 inch per year for each year that the soil around it is allowed to freeze.

In areas where seasonal frost occurs, it is this differential movement that primarily determines the depth to which the waste asbestos must be buried to prevent the eventual re-exposure of the fibers to the air.

Five basic principles govern the selection of a method for the burial of an asbestos deposit in areas subject to seasonal frost. For this purpose, an area subject to seasonal frost is defined as one where significant freezing of the ground (i.e., freezing which alters the original arrangement of the soil grains) occurs in at least one year in 10, or no less than 10 times per century.

The five principles may be set forth as follows:

1. Except for very small deposits, containment of asbestos waste shall be by means of on-site containerization with appropriate soil layers; excavation of material and removal from the site shall be utilized sparingly and as a last resort, and then only in accordance with procedures established for the protection of personnel and the public.

2. Soil layers shall be of locally available materials selected to be of a gradation which allows the movement of air and moisture through the soil; the soil layer immediately in contact with the asbestos deposit shall be a non-frost-susceptible sandy material, with the amount of material (by weight) finer than the #200 sieve (0.074 mm) being no greater than 15% of the material in the sand sizes (0.42 to 0.074 mm).

3. The depth of burial shall be that which is required to keep the frostline from entering the waste deposit in no more than 10 years per century on the average (or, equivalently, 3 years in 30), representing a confidence level of 90%; for this purpose the frostline is defined as the 32^{o}F isotherm (the line joining points having 32^{o}F temperature).

4. A surface treatment shall be selected which is environmentally compatible with (a) the geographic features of the site (including surface and subsurface drainage, topography, and slope), (b) the vegetative species of the locale, (c) the climatic exposure of the site, and

(d) anticipated future uses of the site following restoration. Mature standing vegetation shall be retained as an integral part of the surface treatment to the maximum extent feasible, inasmuch as it secures the asbestos in place, reduces surface runoff, decreases the elevation of the water table, and moderates the climatic exposure of the site.

5. Surface treatments shall be of such type as will eliminate or control erosion, such as riprap of stone or other material, a pavement, or a permanently maintained vegetative cover; the soil immediately below the surface shall be of sufficient character and thickness to support and enhance the long-term effectiveness of the surface treatment (for example, under riprap the soil shall provide stability against slippage; under pavement the soil shall withstand degradation by frost action and applied loads; under vegetative cover the soil shall support growth of the cover).

<u>Methods of Cover Used in New Hampshire to Contain Asbestos</u>

It is important to realize that there is no single set of specific restorative measures that will be equally applicable to every waste-asbestos deposit that may be encountered, even in a localized area such as the J-M site. In the Nashua/Hudson area of New Hampshire, for example, where a large number of disposal sites of waste asbestos have been identified by the State of New Hampshire, more than a dozen such sites have been restored to normal use by EPA-Region I (New England) since 1983, under the provisions of the Superfund legislation. Each site was found to have its own special attributes and problems which required somewhat different treatment. The factor of steepness of slope had to be considered in the design of a permanently stable cover. Furthermore, the climatic exposure of each site was somewhat different from any other, being influenced by orientation to the sun, the degree of shading by trees or shrubs, the openness to wind, and other similar factors.

It is useful to set down standard guidelines which may be used for the majority of deposits in a given region, as we do in the remainder of this paper. However, in the last analysis the basic principles stated above control the selection of a method for restoring a site; these principles have been found to be valid in the cases considered to date.

It is believed that recommended depths determined according to the procedures described here can be relied upon when the basic physical properties of the soils used for the cover are known, and when appropriate and continuing maintenance of the covering materials is provided for. However, the long-term reliability of the methods described here can be fully determined only with the passage of time, together with periodic monitoring of the restored site. For this reason, and the fact that human health is at stake, a recommended thickness of cover must always be on the conservative side.

Table 1 presents basic information on the thickness of soil cover utilized in the Nashua/Hudson area of New Hampshire. Figs. 3(a) and 3(b) illustrate a typical arrangement of the cover layers on gently sloping ground and on steep slopes.

Calculation of Frost Depth at the J-M Waukegan Site

Cover depths calculated here for open areas of the J-M Waukegan site are based on proven practice developed for the underlayment of pavements[1] in areas of seasonal frost by the Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, a Corps of Engineers laboratory specializing in the behavior of materials in cold regions. The general procedure has been validated with more than 30 years of experience by the Corps of Engineers in airfield and highway design. The technique is equally applicable to unpaved areas[2] such as are considered here.

The specific procedure described is a modification which has been developed by the writer for containing waste asbestos near the base of the covering layers for a minimum

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[1] Pavement Design for Seasonal Frost Conditions, Army Tech. Manual No. 5-818-2 and Air Force Manual No. 88-6, Chap. 4, Depts. of the Army and Air Force, Washington, D.C. 22 Jan 1985.

[2] Calculation Methods for Determination of Depths of Freeze and Thaw in Soils, Army Tech. Manual No. 5-852-6 and Air Force Manual No. 88-19, Chap. 6, Depts. of the Army and Air Force, Washington D.C. 5 Jan 1966.

period of 100 years. The actual safe lifetime, i.e., until asbestos begins to reappear at the surface, is probably several centuries when the removal of covering material by erosion or human activities is effectively controlled.

Freezing ground beneath a pavement is designed in type and depth to limit volume change owing to the formation of ice lenses. On the other hand, design for containment seeks to limit migration of the hazardous material toward the surface as the ground freezes and thaws. The parameter being regulated in this case is the number of times the asbestos layer is penetrated by the frost zone over the design period.

Ground freezes because of the removal of heat. It is therefore clear that the depth of frost penetration below the surface is related (1) to the severity of the winter air temperatures, (2) to how closely the ground surface temperature follows the air temperature, and (3) to the thermal properties of the soil used for the covering layers. The coldness of the air temperature is expressed in terms of an air freezing index (F) for each winter in the region of the site, while the efficiency of thermal transfer between the air and the ground surface is expressed in terms of an n-factor (a fraction between 0 and 1) which is a function of the surface character. In combination, the two parameters result in a surface freezing index (nF), which is a measure of the total heat extracted from the ground over an entire winter. The thickness of moist soil (of the type planned to be used for the covering layers) which this quantity of heat will freeze is then calculated utilizing the known or estimated thermal properties of that soil.

The manner in which these parameters are utilized to calculate the required depth of cover for safe burial of waste asbestos at the J-M Waukegan site is described below.

Influence of Air Temperature. The air freezing index for a given area is the total number of Fahrenheit degree-days below freezing (32^{O}F) for the winter season of a single year. It is calculated in exactly the same way as the more familiar heating degree-days, except that for heating purposes the winter temperatures are subtracted from 65^{O}F. If the value of heating degree-days is known, the air freezing index may be calculated from it by a simple technique.

The average daily, or mean monthly, temperatures used for these calculations are those measured by the nearest official station of the National Weather Service. A record of these temperatures is published monthly.[3]

Waukegan, Illinois, is one of the weather stations for which an extended record of temperatures is available. An

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[3] Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951-80, Illinois in Climatography of the United States No. 20 (By State), National Climatic Center, Asheville, NC (Dept. of Commerce), Sept. 1982.

accurate record of many years duration is required because it shows not only the average temperatures likely to occur in a winter, but the warmer and colder years as well and the frequency with which they occur. The temperatures in a region are normally considered to be those of the central station with adjustments for differences in exposure; the air temperatures at the J-M disposal site are assumed to be equal to those at the Waukegan weather station (elev. 700 ft).

For the Waukegan area the air freezing index, averaged over the 30-year period from 1951 to 1980 and calculated from the temperature normals, is 848 degF-days. This value is termed the <u>mean air freezing index</u> for the area. In the absence of additional information, we assume that the mean for the next 100 years will be similar to this value. One hundred years represents an expedient design period for determining the required depth of burial of the asbestos; the actual life-cycle is much greater than this, as previously mentioned.

The freezing index represents the quantity of heat removed from the ground over a winter season; the loss of this heat causes the moisture in the ground to freeze. For moist sandy (non-frost-susceptible) soils such as those normally selected for the burial layers, calculation based on the procedures in references [1] and [2] indicates that the <u>average</u> frost depth for a freezing index of 848 will be approximately 25 in. when the ground has a maintained turf surface and is kept free of snow (Fig. 4). It has been measured, however, that each 4 inches of snow typically reduces the average frost depth by about 10%, because air held within the snow insulates the ground surface. Therefore, if it is assumed that an average of 6 in. of snow remains on the ground in a typical winter (based on precipitation normals), the actual average frost depth in the Waukegan area is 15% smaller, or about 21 in.

It might seem that a soil cover of 21 in. would consequently protect the waste asbestos from freezing and from being brought to the surface where it would again become a hazard. However, 21 in. is not sufficient for the simple reason that <u>average</u> values are normally exceeded over approximately one-half the total time. The result is that in about 50 years out of 100 the frost depth will be greater than this value, with the frost zone extending into the asbestos deposit. This is not considered a safe condition for long-term protection, because the asbestos is likely to move toward the surface in each of those 50 years.

A reasonable criterion for safe burial using a non-frost-susceptible (NFS) soil cover, as is the practice in New Hampshire, is normally taken to be an exceedance level of 10% (equivalent to a confidence level of 90%) which represents an average of 10 freezings into the asbestos per century. (By comparison, expensive, high-quality airfield pavements kept free of snow are designed with an exceedance level of 5%.) We select the appropriate burial depth using an air freezing index calculated for the 3 coldest years in 30, giving an exceedance level of 10% for the 30-year period and presumably over the initial 100 years as well.

Charles Vita of Golder Associates in Seattle, Washington, has calculated probabilities of exceedance at Waukegan for the 35 years of record from 1949 to 1984, determining that the distribution is approximately log normal (Fig. 5). The air freezing index at the 10% exceedance level (probability value 0.10) is approximately 1300 degF-days. It may be found from Fig. 4 that this freezing index corresponds to a frost penetration of approximately 36.5 in. using an NFS sandy soil with a maintained turf surface kept free of snow. An average snow cover of 6 in. would reduce this value by 5.0 in. to 31.5 in. This is the thickness of soil cover that would be required to prevent the frost-line from penetrating the asbestos layer in 90 out of 100 years using an NFS cover layer. Conversely, for each of the 10 years in which a portion of the asbestos layer freezes, some asbestos particles are likely to enter the cover layers and begin the slow but continuous movement toward the surface.

Figs. 4 and 5 may be utilized to estimate the depth of penetration into the asbestos in each of the 10 years of exceedance. For example, an exceedance level of 5% corresponds to an air freezing index of 1500 degF-days which yields a snow-free frost penetration of 41.5 in.; a 6-in.

snow cover would reduce this to 35.3 in. Consequently, in the 5 warmest years of the 10, the frost would extend into the asbestos a maximum depth of 3.8 in. (the difference between 35.3 in. and 31.5 in.). Most of the asbestos particles which could eventually reach the surface would have originated in this 3.8-in. zone. This result assumes an NFS soil as a cover layer.

In a similar fashion it may be determined that with an NFS soil the maximum depth of freeze-in during a typical 100-year period (with snow) would be 45.0 in. less 31.5 in. Thus, an exceedance level of 1% (0.01) corresponding to a freezing index of 1950 degF-days yields a maximum depth of freezing into the asbestos of 13.5 in. for the coldest year in 100.

Influence of Site Exposure. Local exposure factors that affect air temperature, such as wind and solar radiation, also affect the expected frost penetration depth at a particular site. In order to take thee variations into account a degree of climatic exposure is estimated for each site under consideration in a given region.

For simplicity, local climatic exposure is divided into three degrees, primarily based on the availability to wind and its inherent cooling effect: severe, for large, flat or gently sloping areas, with no tree cover; moderate, for medium-sized areas with 5% to 10% slope, which may be intermittently tree- or brush-covered but with little wind-screening; or limited, for areas of any size or slope which are surrounded by woods or other wind-screening barriers, or which have a permanently retained continuous tree cover. These degrees of local exposure are then associated with the 10% level air freezing index in the following way.

The Cold Regions Research and Engineering Laboratory (CRREL) has analyzed the long-term temperature records for weather stations throughout New England[4] and determined the air freezing index for the 10% exceedance level; its value for most stations in New England is given by the equation $F_{.10} = (350 + 1.16\ F)\ (1 \pm 0.05)$, where F is the mean air freezing index for that station. As noted, there was found to be a ± 5 % range in air freezing index value among stations with similar means. This ± 5% variability persisted over a broad range of exceedance values and appears to be indicative of local exposure factors. It is assumed that the Waukegan area would also be subject to this natural variation in local climate.

Accordingly, the average air freezing index value at a given exceedance level is arbitrarily assigned to represent moderate site exposure. Severe site exposure would indicate an air freezing index 5% greater in value, and limited site exposure would indicate an index 5% smaller in value. For the Waukegan area the corresponding 10% level freezing index

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[4]See Footnote 1

values are 1365 (severe exposure), 1300 (moderate exposure), and 1235 (limited exposure), each in units of degF-days. For an NFS soil cover, these indices translate into snow-free frost penetrations of 38.3 in., 36.5 in. (as before), and 34.7 in.

As a whole, the J-M disposal site at Waukegan would appear to be in the category of severe site exposure, inasmuch as it consists primarily of large gently sloping areas with no tree cover. On the other hand, there is a mitigating influence in a warmer-than-normal groundwater; as previously mentioned, the utility plant adjoining the southern edge of the J-M property discharges water into wells at a temperature which maintains the local groundwater at the disposal site some 5 degF above normal. Because the ground would also be warmed, the J-M site is judged to be in the moderate exposure category as a whole.

Open disposal areas at the site are therefore in the moderate exposure category. However, the steep sloping bank bordering the southern boundary is in the limited exposure category, as define here.

Influence of Thermal Transfer. In practice, frost penetration depths for snow-free surfaces may be reduced by a thermal transfer coefficient (n-factor) which varies with the anticipated average snow depth for a site, and which also varies with the character of the surface. The n-factor represents the thermal efficiency of transferring heat and temperature from the air to the ground. The n-factor takes values from 0 to 1; except at these limits n is a fraction. Surface freezing index is given by the product nF, where F is the freezing index at a selected probability value.

As previously mentioned, it has been measured at CRREL that each 4 inches of snow provides a reduction of approximately 10% in the effective freezing index at the ground surface, because of the insulating value of the air associated with the snow. When considering several sites over a region, it is appropriate to estimate or measure the average snow depth as a function of exposure category, with a correspondingly varying n-factor. For practice in the Nashua area of New Hampshire this was done (see Table 1). For application the J-M disposal area in Waukegan, however, where the average depth of snow on the ground in a typical winter is approximately 6 in. based on the precipitation normals, a single n-value for the influence of snow (0.85) is appropriate for the areas of moderate exposure.

It has been measured that frost penetration under a snow cover is approximately proportional to the value of nF, so that in practice penetration depth under snow may be considered to be reduced linearly by the same n-factor.

Furthermore, as mentioned above, each type of surface is also associated with a particular transfer efficiency and consequently a particular n-value. The n for a well-maintained grass turf, which is one type of surface treatment suitable to the open waste areas at the J-M plant, has been measured in the field to be approximately 0.65. These values (n_s; snow; 0.85) and (n_t; turf; 0.65) are utilized in the calculations for a frost-susceptible soil cover which follow.

Influence of Type of Soil Used for Cover. The example of a non-frost-susceptible cover layer, such as a sandy gravel containing very little silt or clay, has been used in the preceding description. This type of soil is considered to be the standard for covering waste asbestos because it tends to trap in-place any asbestos particles that enter the layer from below as the result of frost action. When asbestos is frozen into this type of cover, it moves very slowly because a clean sandy soil forms almost no ice lenses as it freezes.

On the other hand, J-M proposes to use soils taken from a borrow pit in Wadsworth, Illinois, (Fig. 6) as the covering layers. The reasons given by J-M are (1) that this soil is typical of the majority of soils available in the vicinity of the Waukegan disposal site, and (2) clean sandy soils are not readily available in large volume along the western shore of Lake Michigan.

Upon request by EPA-Region V and the writer, J-M provided physical data on the Wadsworth Pit (WP) soils. These data are listed in Table 2; gradation curves are shown in Figs. 7 and 8 for soils WP-2 and WP-4, which appear to be typical of the soils available from the borrow pit.

There is a problem with using the Wadsworth Pit soils for covering layers: percentages of material finer than the 0.02 mm size being in the range 77 to 95 percent, together with high percentages of clay and organics, cause these soils to be highly frost susceptible. The result is that any asbestos particles entering the cover layers from below will migrate rapidly toward the surface; although exact rates of movement are not known, it is clear that rate of migration increases with the intensity of ice lens formation. Consequently, the use of a frost-susceptible soil for covering waste asbestos represents a shorter-term solution to the medical hazard than does the use of a non-frost-susceptible soil.

To counteract this effect, the initial design of the covering layers must be more conservative than described above for an NFS soil. Instead of 10 freezings of the asbestos layer per century, only 5 freezings or perhaps none should be allowed. The conclusion is that a greater thickness of cover must be utilized in order to attain the same degree of protection that 10 freezings per century below an NFS cover would represent.

To determine the required cover thickness using the Wadsworth Pit soils, the physical properties of these soils (compacted density and water content, Atterberg Limits, gradation, specific gravity, and classification according to the Unified Classification system) were compared with those of similar soils that had been tested for freezing behavior by CRREL. The writer was involved in the development and use of this test at CRREL, and is familiar with the soils tested. The freezing test results are tabulated in the reference at Footnote 1.

Assuming a probability of exceedance of 5% (0.05) (representing an average of 5 freezings of the asbestos per 100 years) and using the results of the freezing tests to estimate frozen densities, water contents, and thermal conductivities, the same procedure as described earlier for sandy soil was used to calculate the required cover thickness of the J-M Waukegan disposal site. This procedure is based on the Modified Berggren equation which determines frost penetration depth as a function of surface freezing index (nF), thermal conductivity (K), and volumetric latent heat of fusion (L), modified by a coefficient (λ)which compensates for differences in temperature propagation within the soil mass resulting from the applied heat extraction not being brought about by a single step-change of surface temperature.

The Modified Berggren equation for calculation of frost penetration is given by

$$x = \lambda \sqrt{\frac{48 K n F}{L}}, \qquad (1)$$

where x = frost penetration; (ft)

$K = 1/2\ [K_U + K_F]$

= average thermal conductivity (unfrozen/frozen); (Btu/ft-hr-$^{\circ}$F)

n = surface thermal transfer coefficient (non-dimensional)

F = air freezing index; (^{o}F-days)

L = 144 $\gamma_d \cdot w$

= volumetric latent heat of fusion; (Btu/cuft)

γ_d = average dry unit weight (unfrozen/frozen); (lb/cuft)

w = average water content by weight of solids (unfrozen/frozen); (non-dimensional)

The manner in which eq. (1) was used to calculate frost penetration in the open areas of the J-M disposal site is indicated in the following diagram:

n = 1 (bare grd.)
n = 0.65 (turf)
n = 0.85 (snow, 6 in.)

WP soil

Test soil

Pe = 0.05; moderate exposure; F = 1500

$$x = \overset{0.70}{\lambda} \sqrt{\frac{48 \cdot \frac{1}{2}\left[K_u + K_F\right] \cdot nF}{144 \cdot \frac{1}{2}\left[(\gamma_d \cdot w)_u + (\gamma_d \cdot w)_F\right]}} \qquad (2)$$

WP Soil

Test Soil

Among the results of the freezing tests three soil types were found, the properties of which compared closely with the Wadsworth Pit (WP) soils. These were Minnesota Silt, New Hampshire Silt, and WASHO Clay. (This last soil was the natural subgrade under a series of full-scale pavement sections designed and tested by the Western Association of State Highway Officials some years ago.) Tabulated results of the freezing tests at CRREL confirmed that all of these soils were frost susceptible, exhibiting medium to high heave rates (3.5 to 15 mm/day) and medium to high frozen water contents (31 to 87%). Frost classifications were (M-H), (VH), and (H), respectively (i.e., medium-to-high, very high, and high). It was therefore considered that the Wadsworth Pit soils were also highly frost susceptible, requiring an especially conservative design for cover thickness.

Physical properties of the two major WP soils and the three comparison soils are listed in Table 2. A summary of the gradations is given in Fig. 9. Results of the calculations for depth of penetration in these soils are given below.

<u>Required Cover Thickness for Open Disposal Areas</u>. Using the procedure diagrammed as eq.(2), three levels of frost penetration were calculated: (a) bare ground (snow-free); (b) turf or grass (snow-free); (c) turf or grass with 6-in. average snow depth. For air freezing index, Charles Vita's calculations based on NOAA data were checked and found to be correct, as were the resulting probability values. A probability of exceedance equal to 0.05 was used; the corresponding freezing index was 1500 degF-days. Wadsworth Pit soil data on densities and water contents were used for the unfrozen soil parameters; freezing test data from the comparison soils were used for the frozen soil parameters.

Vita's choice of λ-value (0.70) was accepted and used, although it is about 10% smaller than the writer had calculated.

Kersten's test estimates of thermal conductivity based on density and water content were utilized for both unfrozen and frozen soils. Thermal conductivities for the unfrozen soils were all similar, being in the range 0.80 to 0.90 Btu/ft-hr-$^{\circ}$F.

Surface transfer coefficients (n-factors) used were:

(a) bare ground, n = 1

(b) turf (snow-free), n = 0.65

(c) turf with 6-in. snow, n = 0.85, applied linearly to penetration depth, per field experience

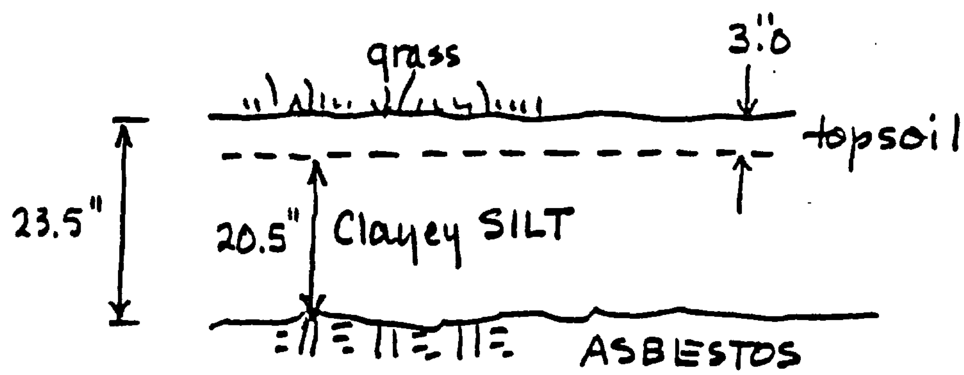
Results are presented in Table 3.

TABLE 3

CALCULATED PENETRATION DEPTHS
USING WADSWORTH PIT SOILS (SILTS)

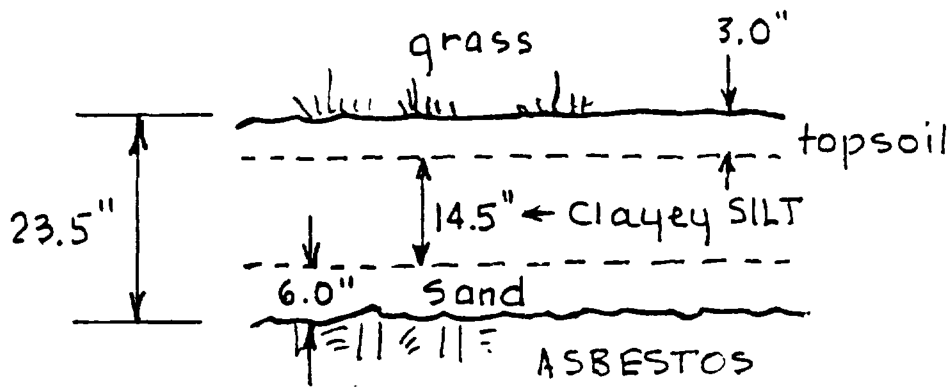
Surface Characteristics	Test Soil (as Frozen)		
	MIN-3	NH-29A	WASHO-1,5-7
a. bare ground	37.3 in.	36.6 in.	37.3 in.
b. turf (snow-free)	30.1	29.8	30.1
c. turf; 6 in. snow	25.6	25.2	25.6

Required Profile for Cover Layers. Based on the calculations outlined above, it is concluded that a total thickness of 26 in. is required to prevent asbestos from reaching the surface in a reasonable time (well in excess of 100 years) given present-day climate at the J-M disposal site in Waukegan, Illinois. This value is for uncompacted soil layers. Inasmuch as J-M proposes to construct the cover with compaction, however, bringing initial densities from approximately 95 pcf to 105 pcf, a reduction of some 10% is allowable. The profile based on compacted silt would then total about 23.5 in. in thickness:



(a)

However, a modified profile is preferred that includes a barrier layer of sand adjacent to the asbestos, conforming to the principles of design previously discussed; particles would tend to remain in the sand layer, increasing the total life of the cover:



(b)

Calculation shows that the substitution of clean sand for the clayey silt <u>increases</u> the frost penetration by about 2.0 in. Because of the barrier effect of the sand, however, it becomes allowable to apply the standard probability of exceedance (0.10) to this profile. The corresponding air freezing index is 1300 degF-days; calculation of frost penetration using this value <u>reduces</u> the total thickness by 2.0 in. Both profiles are therefore about 23.5 in. in total thickness, which is rounded upward to 24 in. However, profile (b) represents a longer-term (and safer) solution than does profile (a).

<u>Evaluation of Proposed 18-in. Profile by J-M</u>. The cover thickness proposed by Johns-Manville Corporation for the open areas is an 18-in. total thickness, 3 in. of which is topsoil to support a grass (turf) surface treatment. The apparent

savings is about 10 percent of the total construction cost, amounting to approximately $400,000 by their estimate. Justification by J-M for this proposed thickness is based on the calculations by Charles Vita of Golder Associates using a computer model of a migrating asbestos particle.

The model may fairly represent the physical reality; it is impossible to say that it is accurate, however, because of the assumptions that have been made pertaining to movement rate which have no counterpart in measured values.

Even so, the results he has presented to support the proposed 18-in. thickness (ltr. of November 6, 1986, p. C-1 and p. C-17 of the Feasibility Study) do not in fact serve that purpose. The estimate utilizing the parameters S = 30%, F= 0.3, representing the heaving strain of the frozen soil and the heave fraction not recovered on thawing, fits the Wadsworth Pit soils fairly well. But the results he cites for these boundary conditions indicate that asbestos will reach the surface in 79 years (lower bound 71 years) if the cover is 1.5 ft in thickness; this result actually represents <u>failure</u> of the cover, because in every year beyond the 79th year asbestos is in contact with the atmosphere, where it again represents a potential medical hazard.

On the other hand the 154 years cited as a lower bound for the 2.0-ft cover thickness <u>does</u> appear to represent a safe condition, in that the total estimated years for objects to appear on the surface is 493 years on the average (p. C-17 of the Feasibility Study) and the probability of exceedance is 100/15 = 0.07, giving a confidence level of 93%. These parameters satisfy the design requirements.

The expedient design life of 100 years chosen for the purpose of calculation does not imply that failure may be accepted shortly thereafter. On the contrary, the design principles imply that almost the original degree of protection provided by the soil cover will remain after the first 100 years following restoration of the asbestos deposit. The intent of choosing a surface treatment compatible with the local ecology, together with the selection of a non-frost-susceptible soil at least at the base of the cover, are for the purpose of improving the stability and reliability of the covering system. The protection provided at the outset should not only be intact at the end of the first 100-year period; the protection should remain for an indefinite period thereafter.

The cover thickness of 1.5 ft of frost-susceptible soil proposed by J-M in the Feasibility Study does not provide these qualities and is therefore not acceptable in its present form.

* * *

Table 1

Station: Nashua, NH
Air Freezing Index (30-yr mean): 665 degF-days
Air Freezing Index (10% Exceedance Level): 1120 ±5% degF-days

Degree of Exposure	Air Freezing Index (F) °F days	* Depth of Frost penetration (h) (in.)	Average Snow Depth (in.)	n	Surface Freezing Index (nF) °F-days	Percent reduction (1-n) %	Reduced Depth of Penetration (1-n)(h) (in.)	* Design Cover Depth (in.)
Severe	1175	33.5	4.0	0.90	1060	10	30.2	30
Moderate	1120	32.0	6.0	0.85	950	15	27.2	27
Limited	1065	30.5	8.0	0.80	850	20	24.4	24

*Design soil for cover layer is moist, sandy (100 pcf; w = 15%).

TABLE 2
SOIL PROPERTIES

Sample No.	Classification or Name	Symbol	Nat. WC	Spec. Grav.	LL	PL	PI	Opt. Dens.	Opt. WC	pH	-0.02 mm
			%					pcf	%		%
WP-2	Clayey Silt with Organics	CL-OL	26.2	2.60	47.9	20.2	27.7	106.8	16.5	-	95
WP-4	Clayey Silt with Organics	CL-OL	17.5	2.63	27.6	17.8	9.8	108.8	16.5	-	77
MIN-3	Minnesota Silt	ML	23.0	2.62	36.0	30.9	5.1	107.1	-	-	63
NH-29A	New Hampshire Silt	ML-CL	20.0	2.70	26.5	20.5	6.0	106.7	16.5	-	73
WASHO-1	WASHO Clay	CL-OL	24.4	2.58	37.0	24.0	13.0	99.6	21.0	-	65
WASHO5,7	WASHO Clay	CL-OL	25.3	2.58	37.0	24.0	13.0	99.6	21.0	-	65
WP-1	Topsoil (Clayey Silt w.sand)	CL-OL	24.1	-	-	-	-	-	-	6.9	31
WP-3	Topsoil (Clayey Silt w.sand)	CL-OL	15.9	-	-	-	-	-	-	5.9	97
WP-5	Silty Clay with orgs.	CL-OL	22.5	2.61	37.0	17.3	19.7	-	-	-	88
JM-1	Fine Sand	SP	-	2.65	-	-	-	-	-	-	0

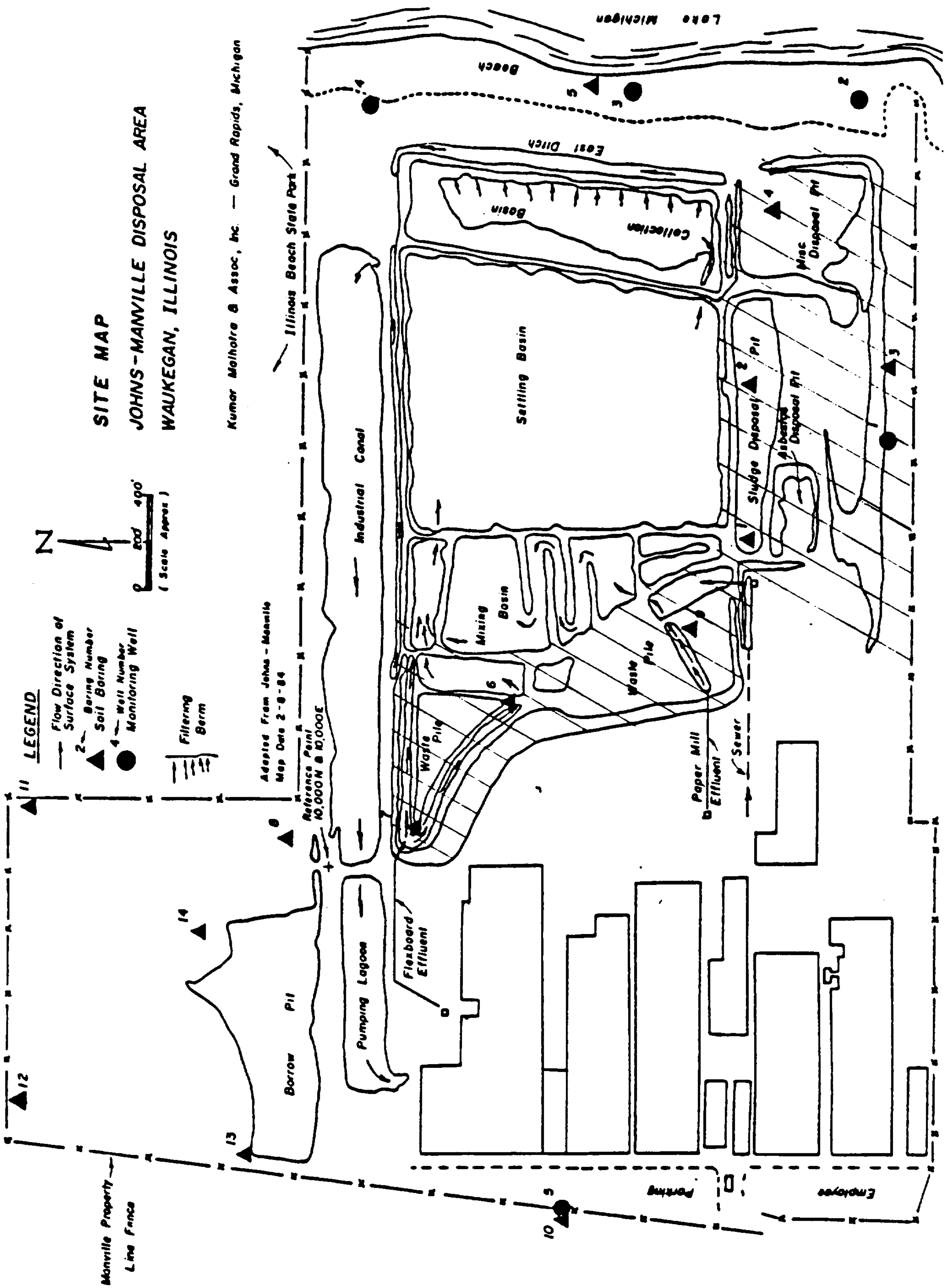


Fig. 1. Site plan of Johns-Manville manufacturing plant and asbestos disposal area, Waukegan, Illinois (open disposal areas are hatched).

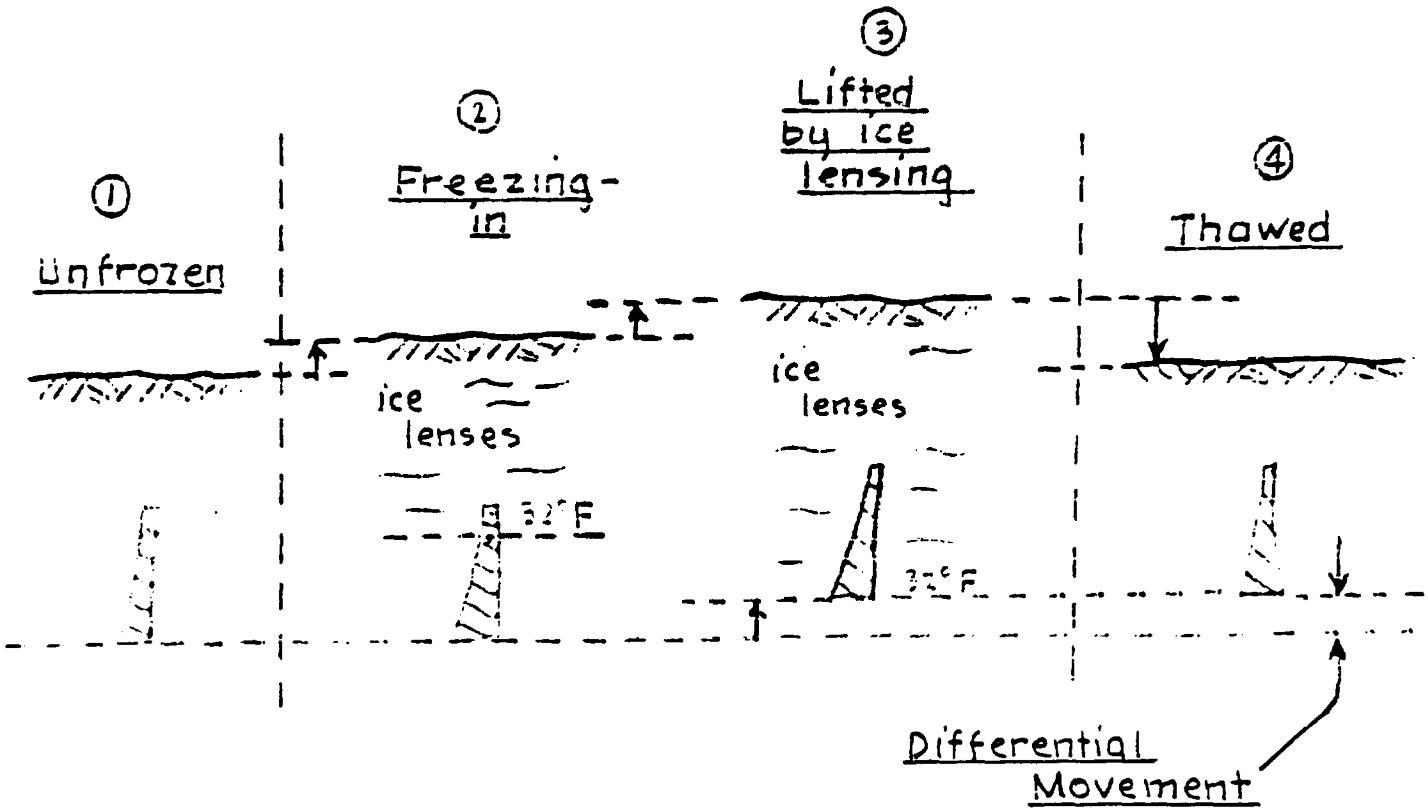
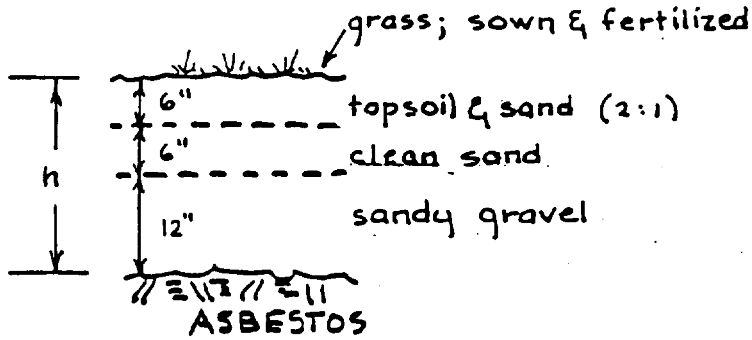
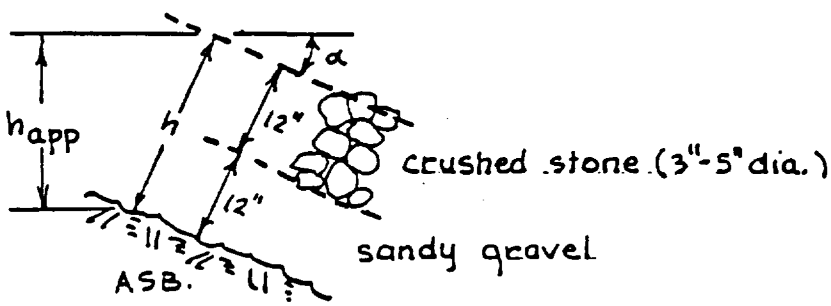


Fig. 2. Schematic illustration of upward movement of asbestos scraps with freezing and thawing.

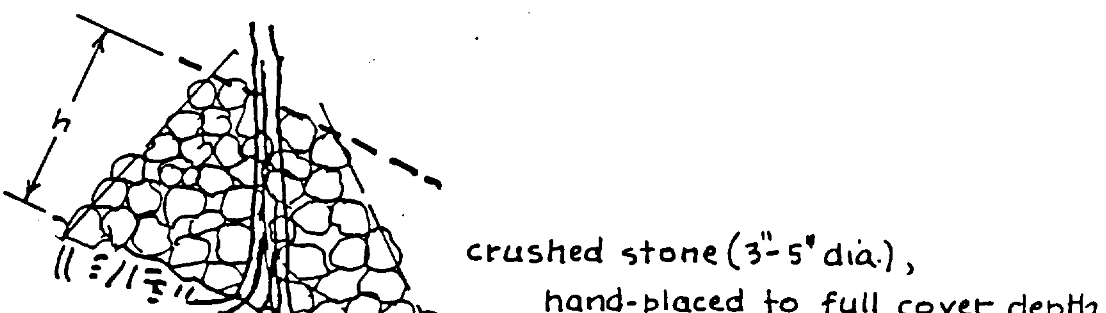


(a) Level or gently sloping ground; effective cover: h = 24".



(b) Steeply sloping ground (α > 10°); effective cover: h = 24".

NOTE: apparent cover depth h_{app} (measured vertically) is less than h; $h_{app} = h \sin\alpha$.



(c) Treatment of roots on all slopes and flat ground.

NOTE: all trees ≥ 3" dia. to be retained.

Fig. 3. Typical soil cover arrangements used to contain asbestos waste in the region of Nashua, New Hampshire (mean air freezing index 665 degF-days).

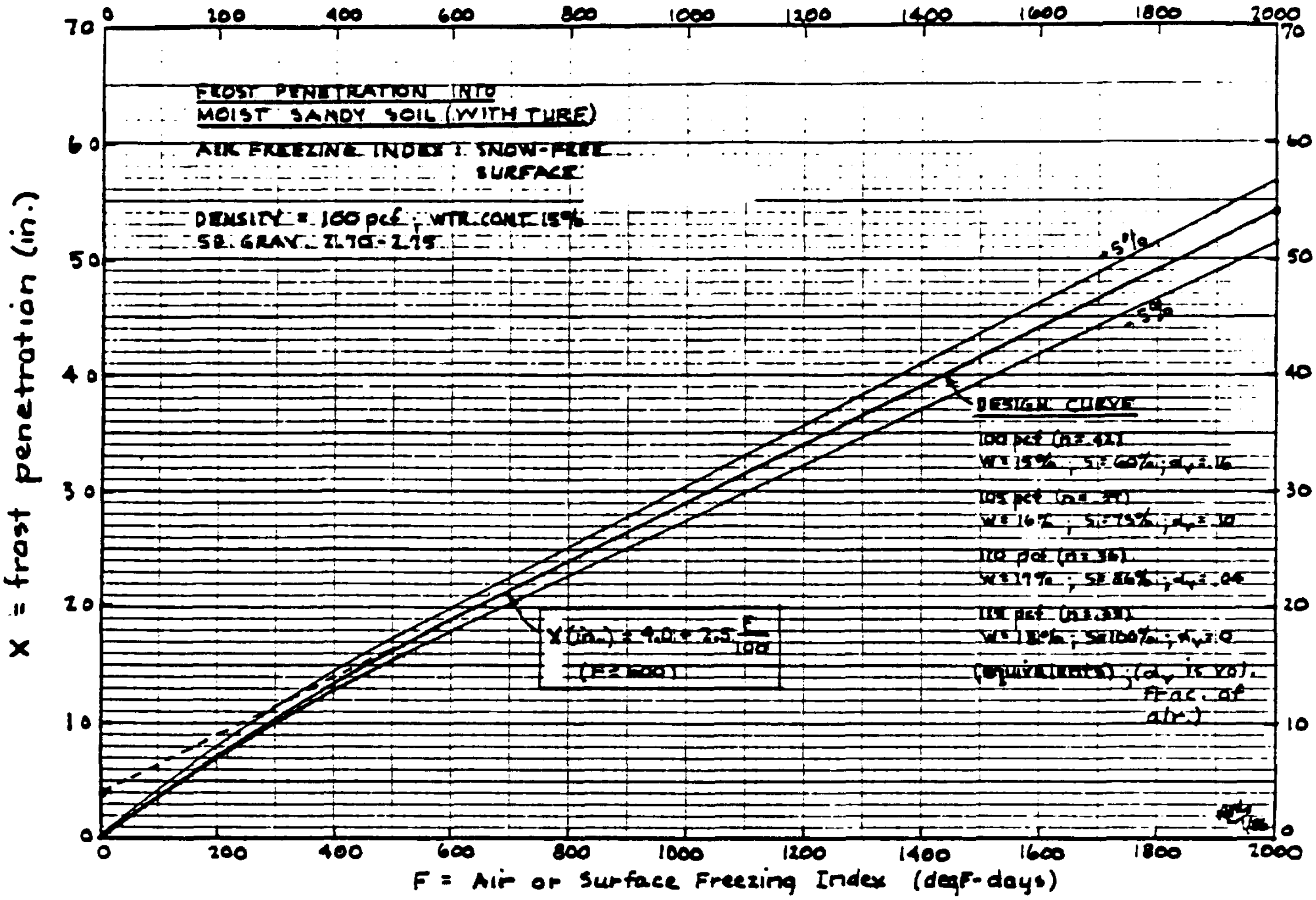


Fig. 4. Frost penetration vs. air freezing index for moist sandy soil (non-frost-susceptible) with a snow-free turf surface; based on Modified Berggren equation.

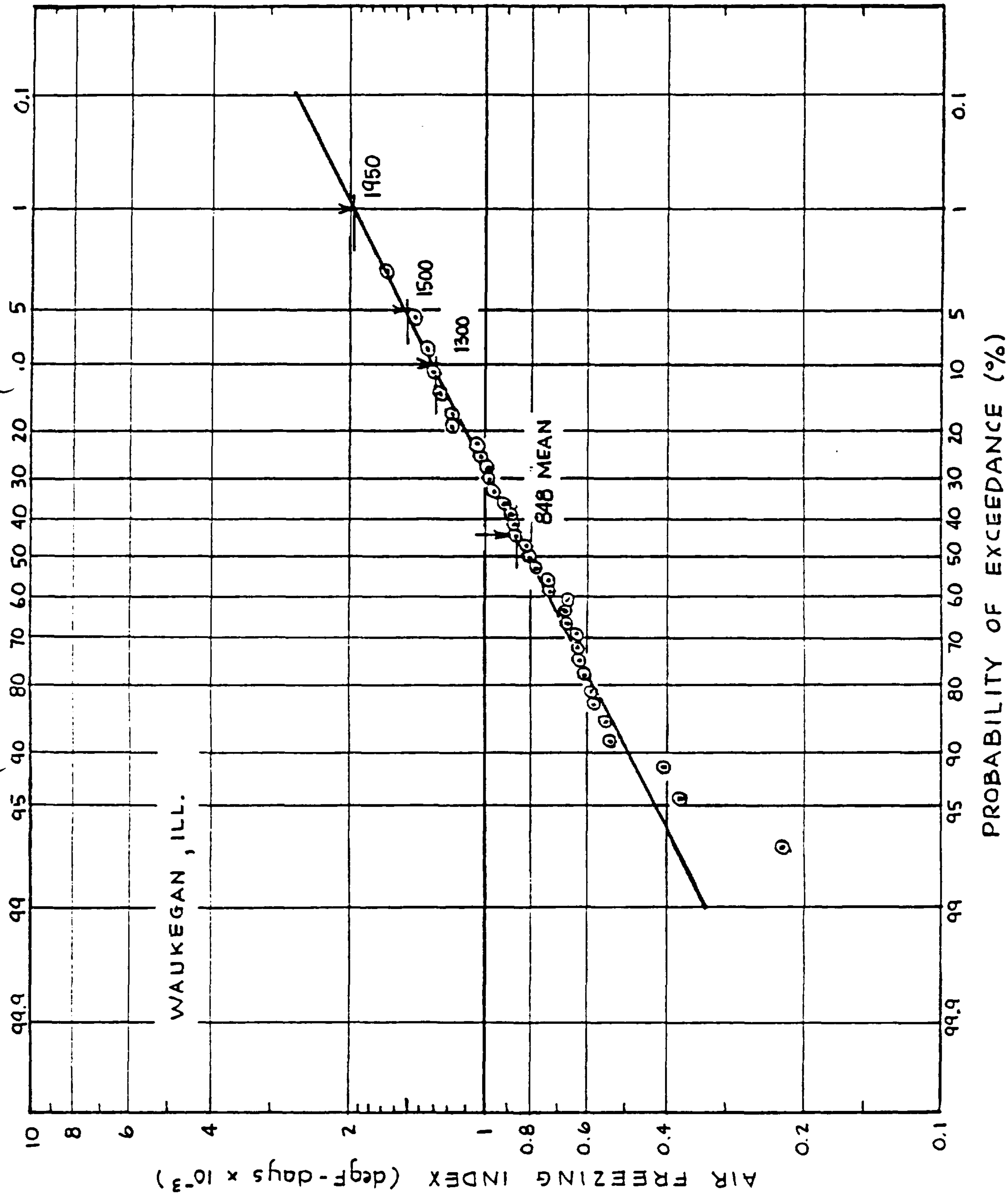


Fig. 5. Air freezing indices for Waukegan, Illinois, with probability of exceedance shown as log-normal distribution (after Charles Vita, Golder Associates).

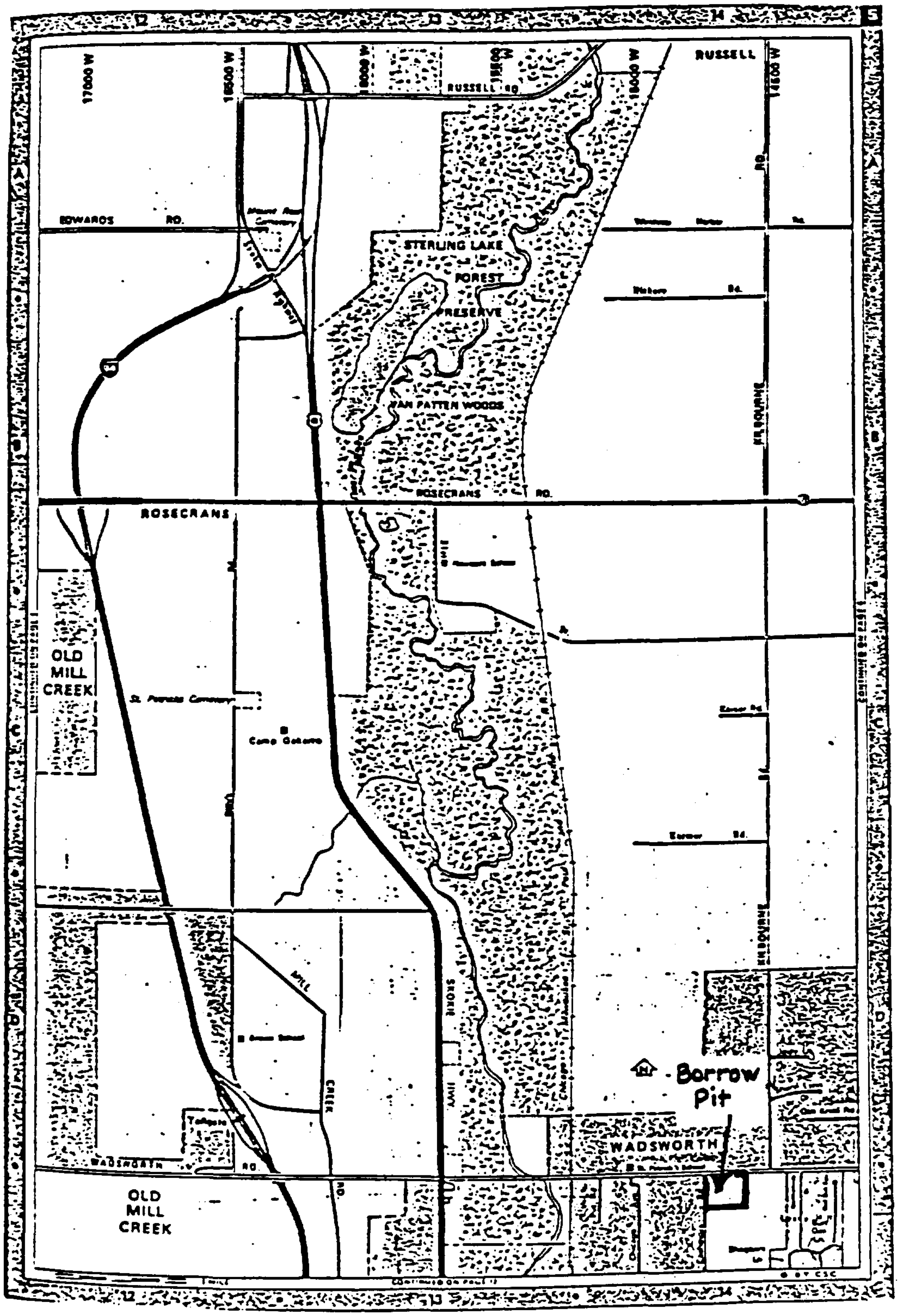
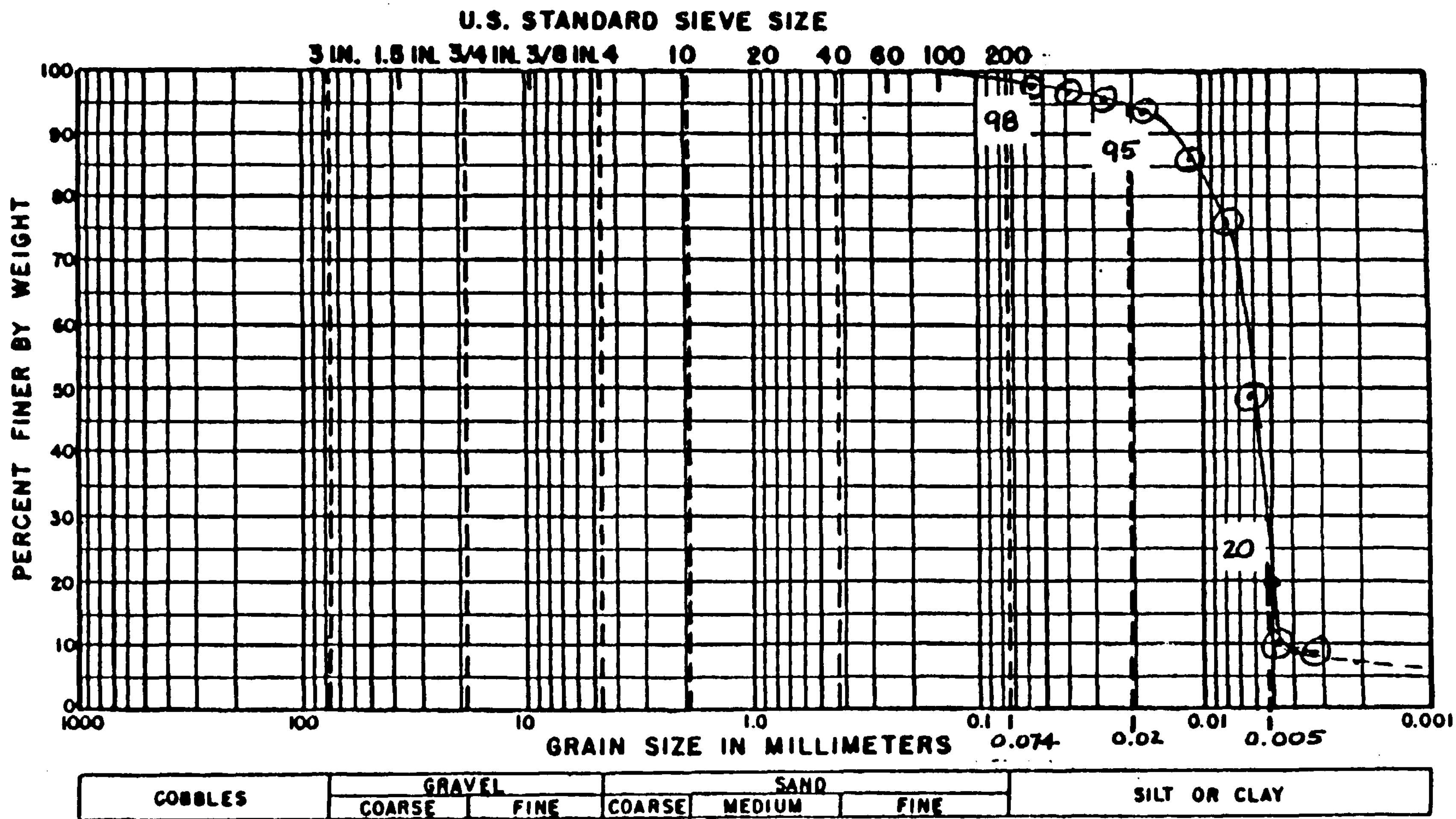


Fig. 6. Site location of Wadsworth Pitt Borrow area, Lake County, Wadsworth, Illinois.

H. H. HOLMES TESTING LABORATORIES, INC.



	DEPTH	CLASSIFICATION	NAT. WC	LL	PL	PI	
WP-2	1.0 ft	CL-OL	26.2	47.9	20.2	27.7	SE section of Pit

Brown & Gray Clayey Silt

GRADATION CURVE

Fig. 7. Gradation of Wadsworth Pit soil WP-2.

Fig. 8. Gradation of Wadsworth Pit soil WP-4.

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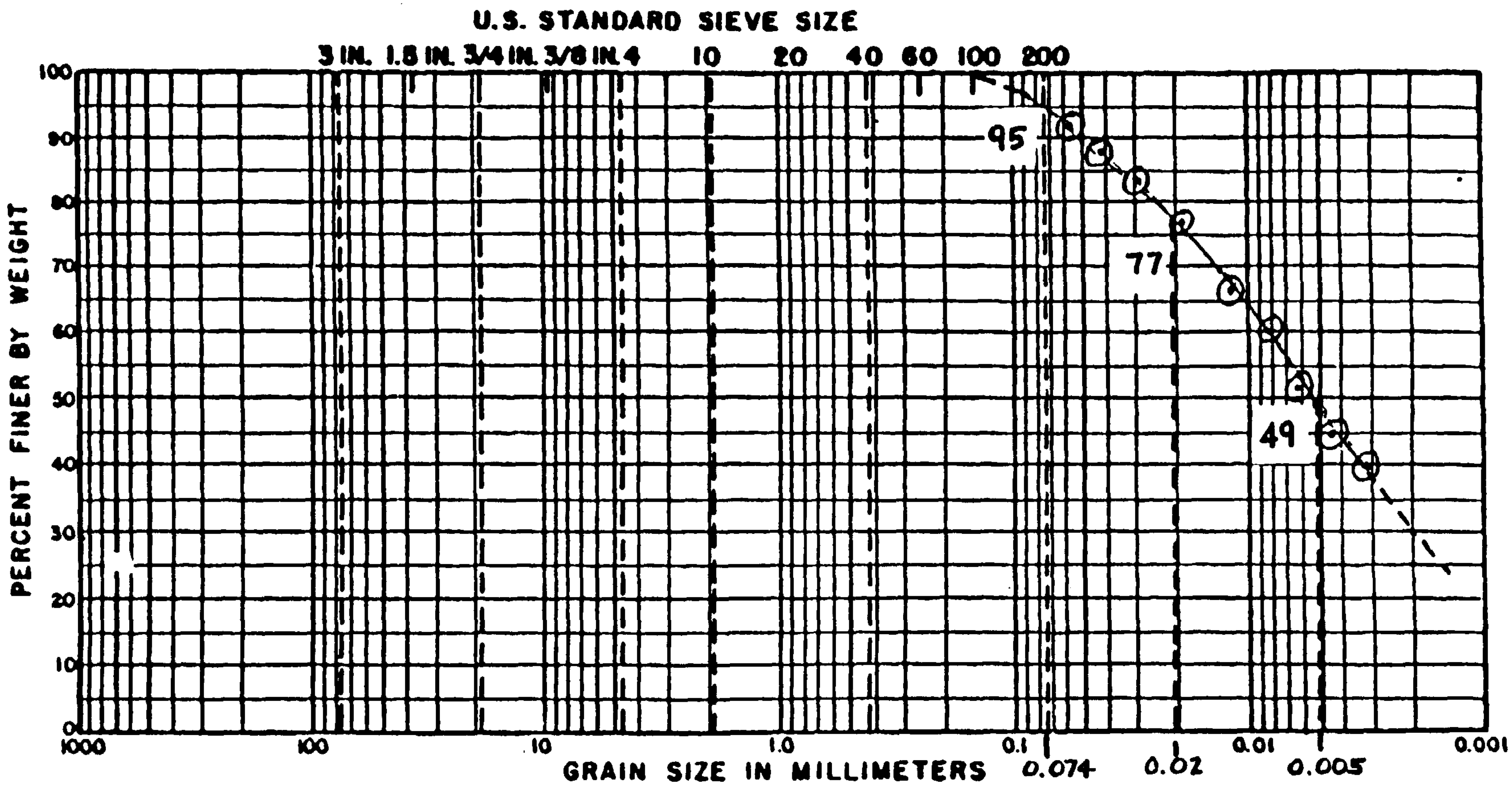
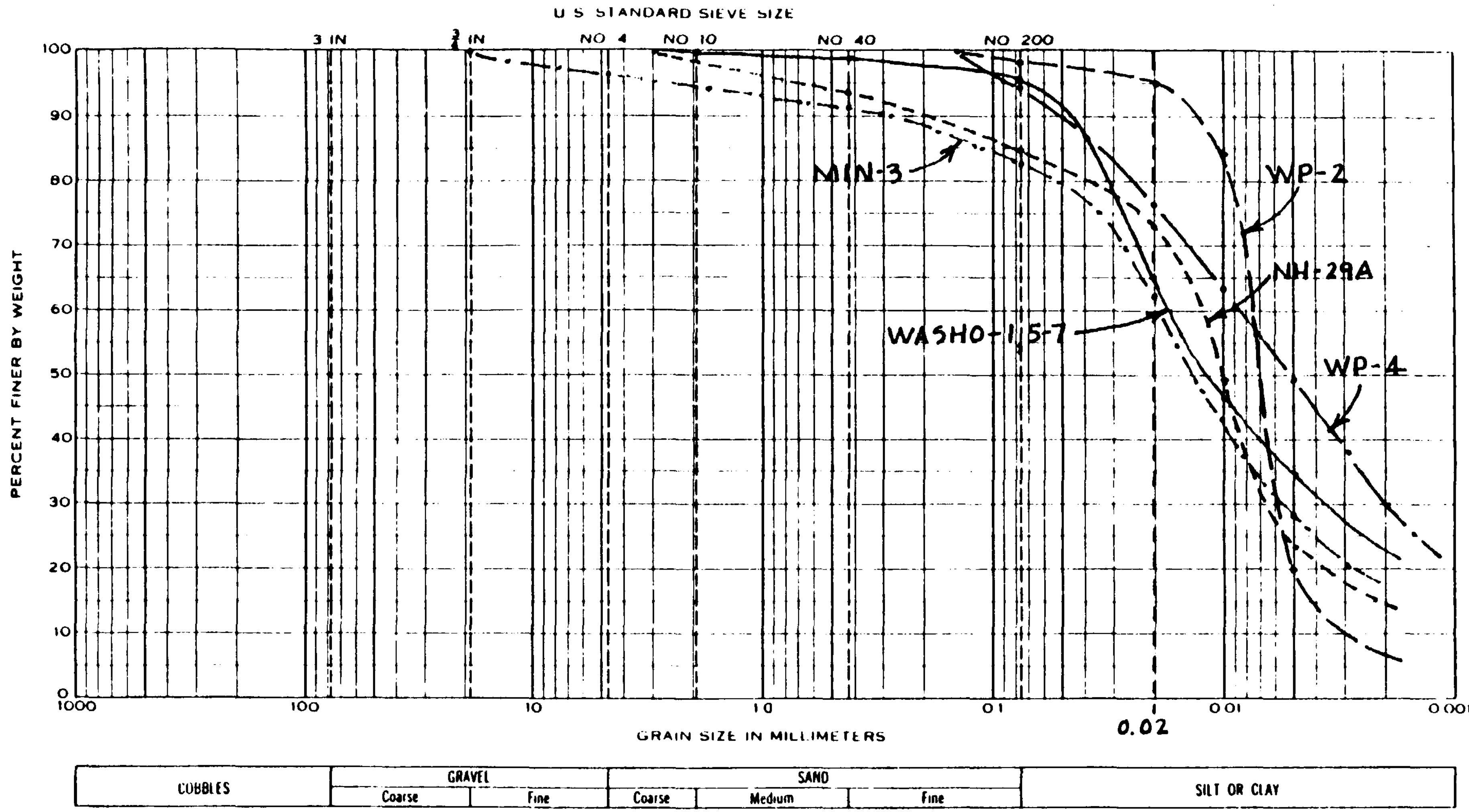


COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

	DEPTH	CLASSIFICATION	NAT WC	LL	PL	PI	
WP-4	1.0 ft.	CL-OL	17.5	27.6	17.8	9.8	W. end of Pit

Brown Silty Clay

GRADATION CURVE



Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	Sp. Grav.
WP-2		Clayey Silt w. Orgs.	26.2	47.9	20.2	27.7	2.60
WP-4		" " "	17.5	27.6	17.8	9.8	2.63
MIN-3		Minnesota Silt	23.0	36.0	30.9	5.1	2.62
NH-29A		New Hamp. Silt	20.0	26.5	20.5	6.0	2.70
WASHO-1	5-7	WASHO Clay	25.0	37.0	24.0	13.0	2.58

GRADATION CURVES

Project WAUKEGAN, ILL.

Area J-M DISPOSAL SITE

Boring No.

Date

2087 (Translucent) (EM 1110-2-1801)

Fig. 9. Summary of gradations of WP soils and CRREL freezing-test soils.